Where are the malaria vectors?

Identification and uncertainty associated with classification of *Anopheles* habitat using remote sensing

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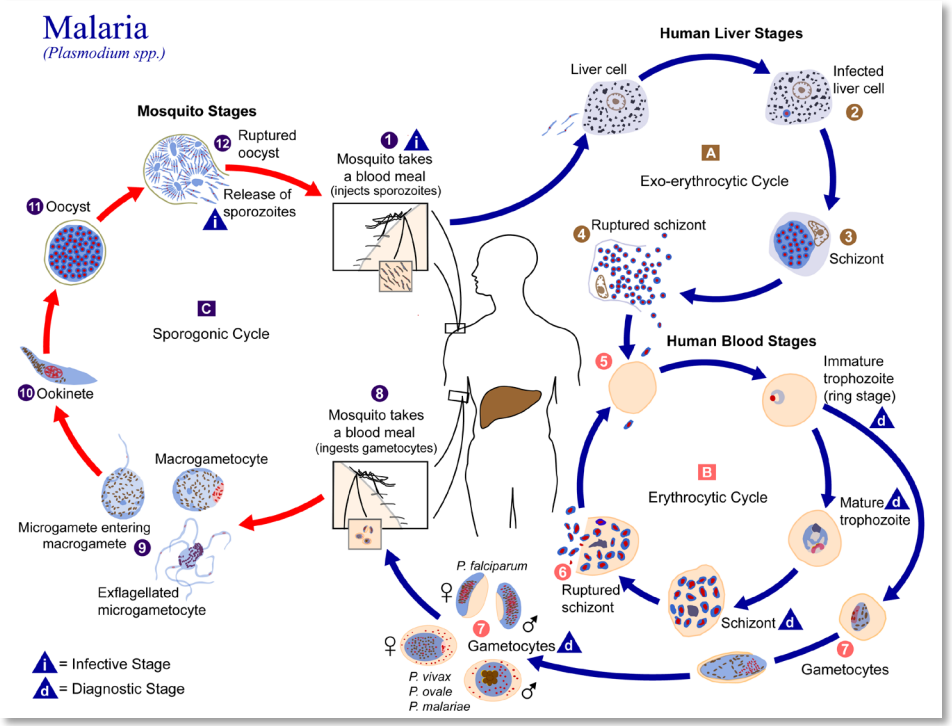
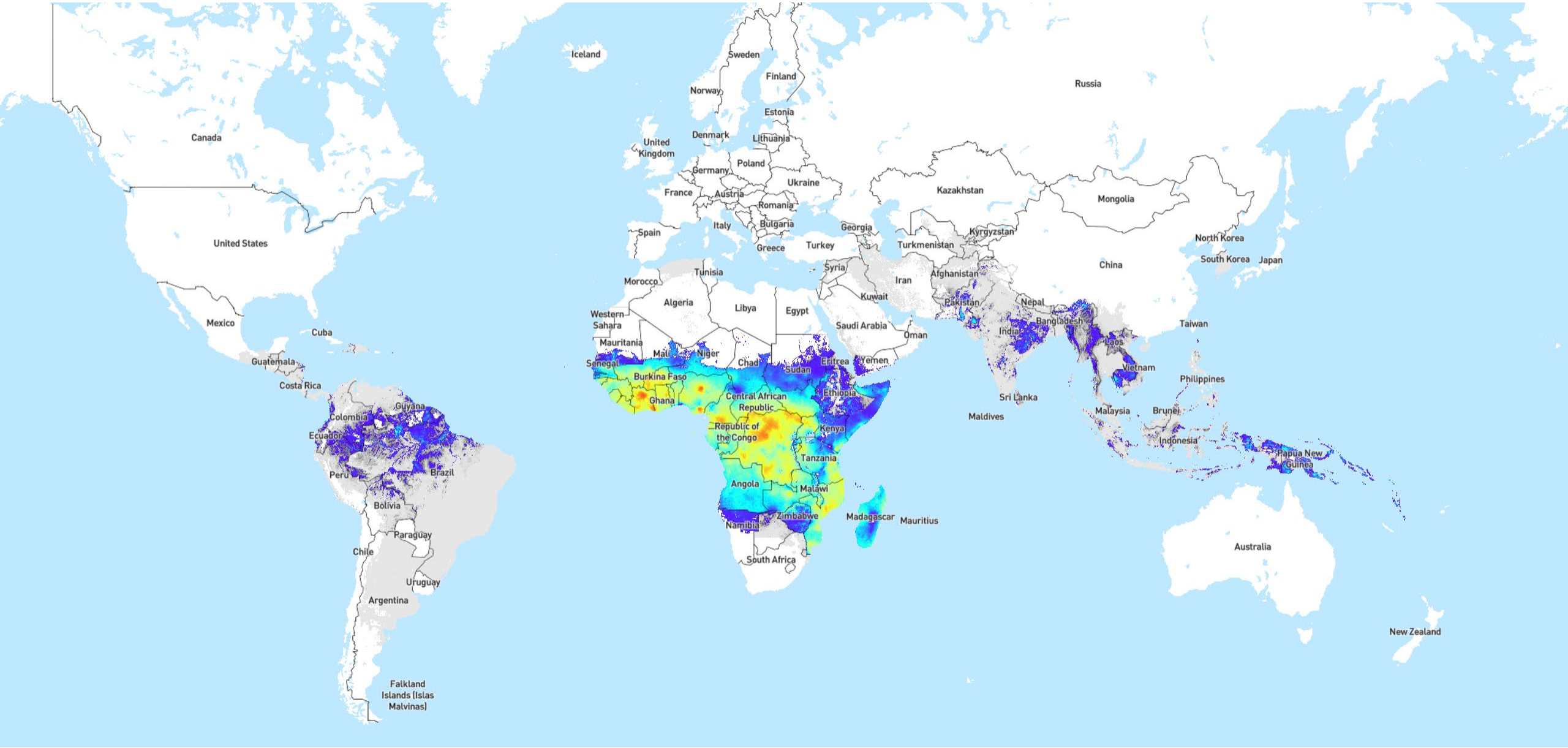
Plasmodium falciparum malaria

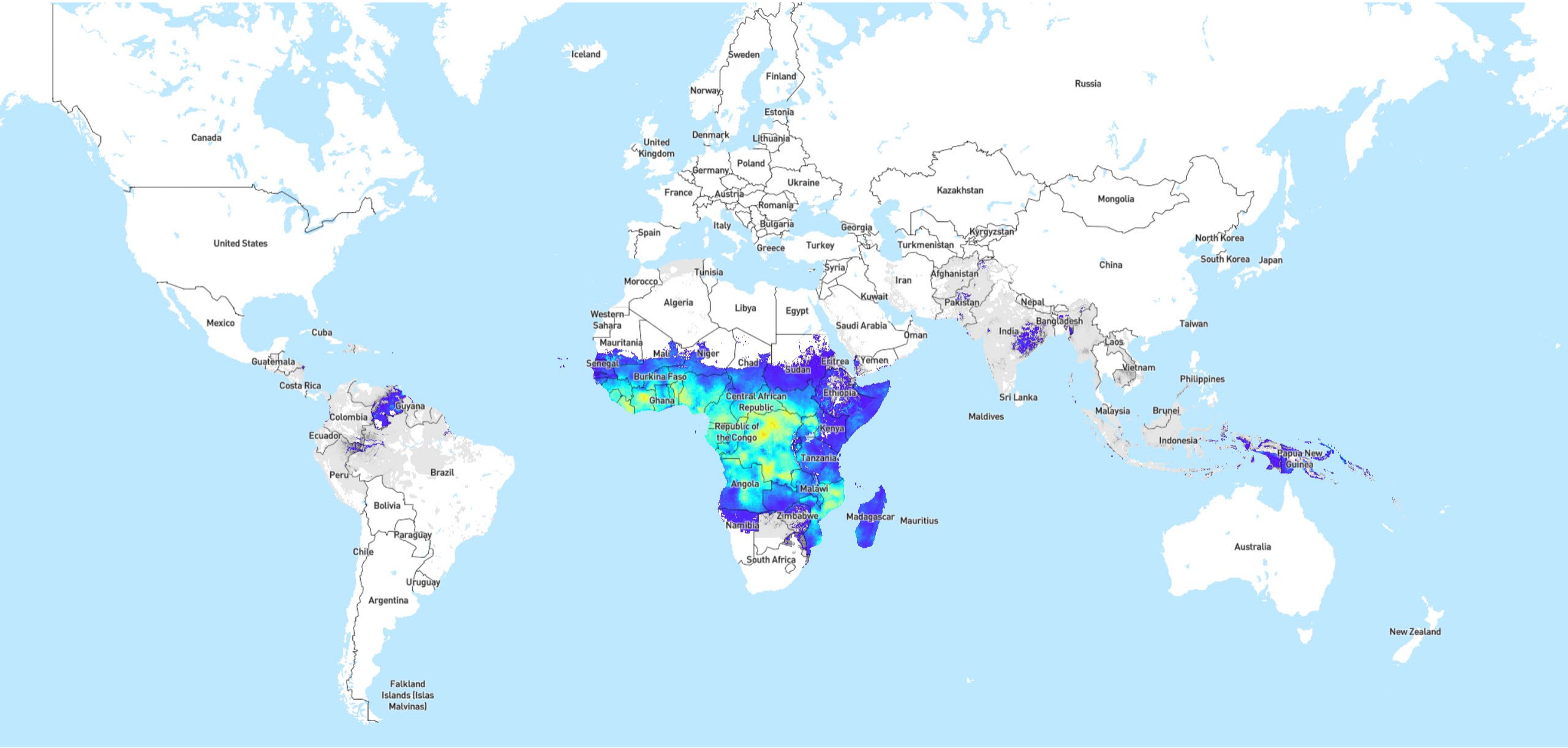
- 241 million cases, 627 thousand deaths in 2020 (WHO 2021)
- Most of the malaria burden is in Sub-Saharan Africa, children under five
- Obligate human parasite
- Spread via mosquitoes



CDC (2002) *Public Health Image Library*



Malaria Atlas Project | *Pf*PR$_{2\text{-}10}$ in 2000



Malaria Atlas Project | *Pf*PR$_{2\text{-}10}$ in 2019

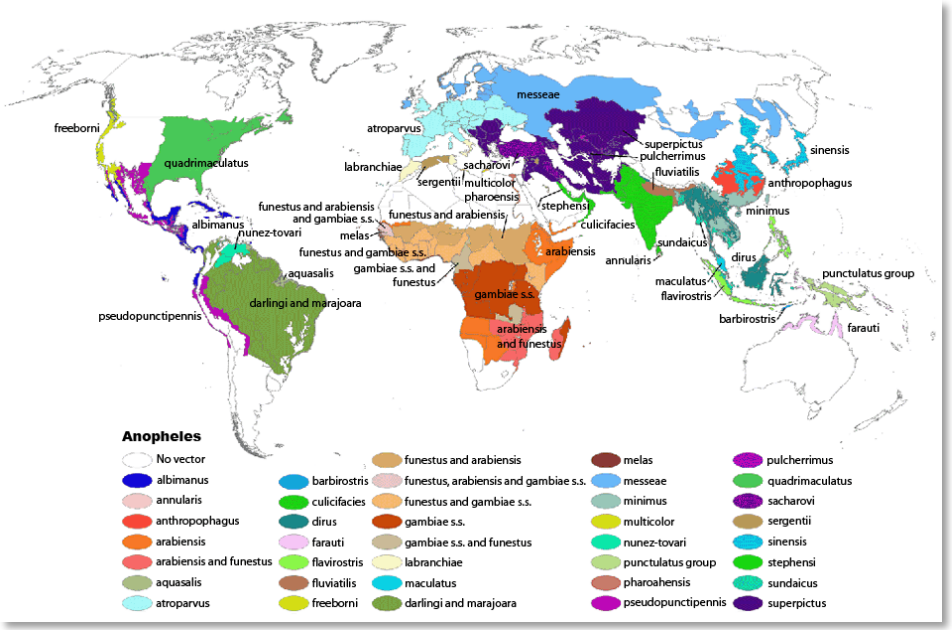
Malaria vectors

- Solely *Anopheles* genus mosquitoes
- Over 100 *Anopheles* species can transmit malaria, 30 to 40 species are the most common
- Presence of *Anopheles* does not mean that malaria is present, but presence is a requirement for the parasite to be present

CDC (2014) *Public Health Image Library*

Malaria vectors

- *Anopheles* genus is distributed throughout the world
- Typically, the malaria parasite is eliminated from a region, not the mosquito
- Each species of the *Anopheles* genus has bounds for their habitat
  - Moisture / rainfall
  - Average temperature
  - Minimum/maximum temperature



Kiszewski et al. (2004)

So where are they?

Environmental Envelopes

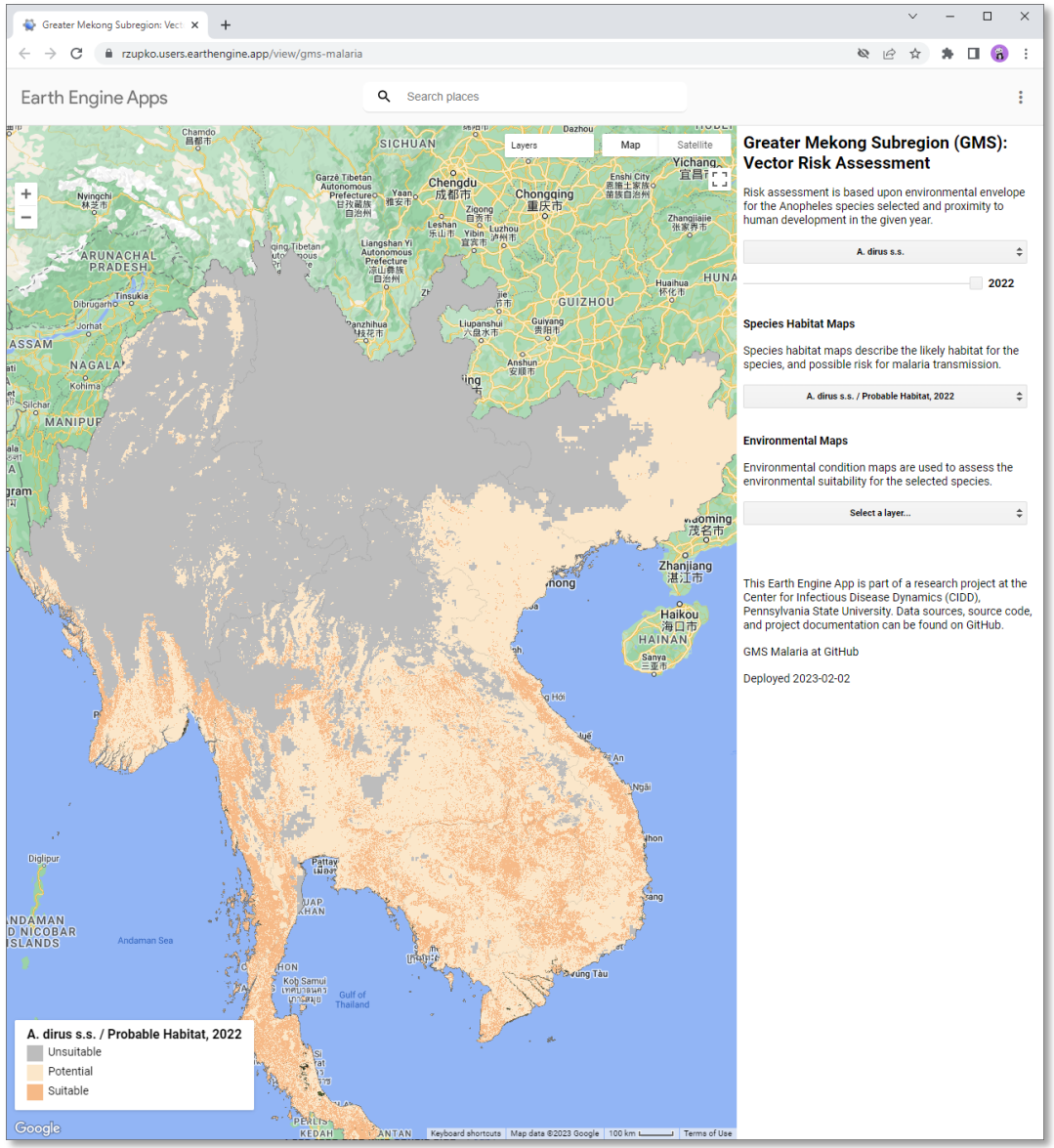
- Habitat identification based upon environmental envelopes (Obsomer et al. 2012)

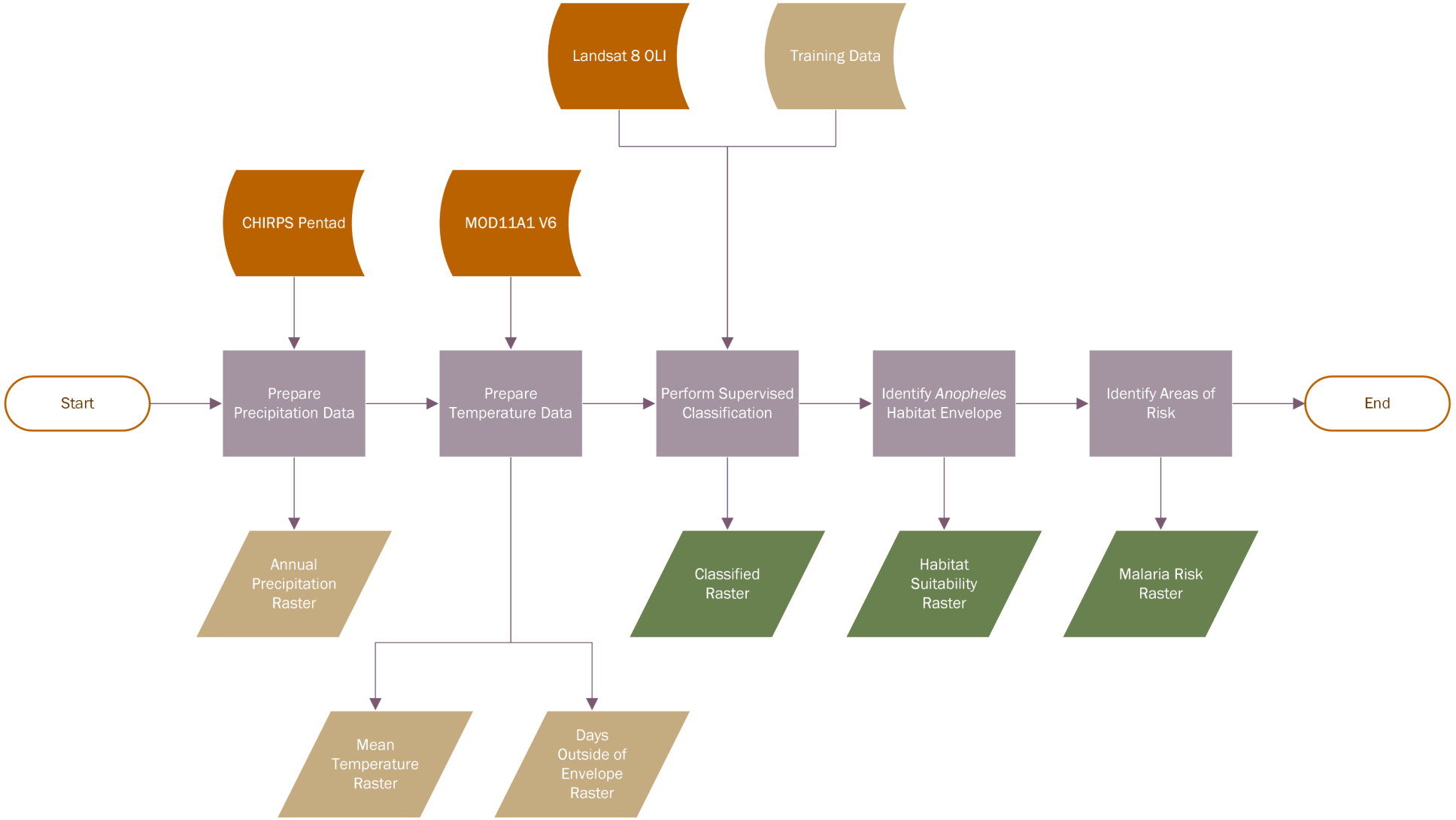
- Possible *Anopheles* habitat identified based upon precipitation, temperature, and landcover (i.e., forests)

	A. baimaii	*A. crascens*	*A. dirus s.s.*	*A. dirus s.l.*	*A. scanloni*
Total annual precipitation (mm)	> 1200	> 2000	> 1500	> 1500	> 1500
Minimum temp coldest month (°c)	> 12.5	> 20	12.5 - 21	12.5 - 21	> 15
Maximum temp coldest month (°c)	< 28	< 28	< 26	< 26	< 28
Mean of mean monthly temp (°c)	24 - 27.5	> 25	24 - 27.5	24 - 27.5	> 25
Mean of mean SD (°c)	0.5 - 2.5	0 - 1.0	0.5 - 2.5	1.0 - 5.0	0 - 2.0

Analysis

- Google Earth Engine
  - JavaScript (web-browser)
  - Python (scripted automation)
- Datasets
  - CHIRPS Pentad (precipitation)
  - MOD11A1.061 (temperature)
  - Landsat 7, 8 (imagery)
- Landcover classification
  - Supervised training
  - Classification And Regression Tree





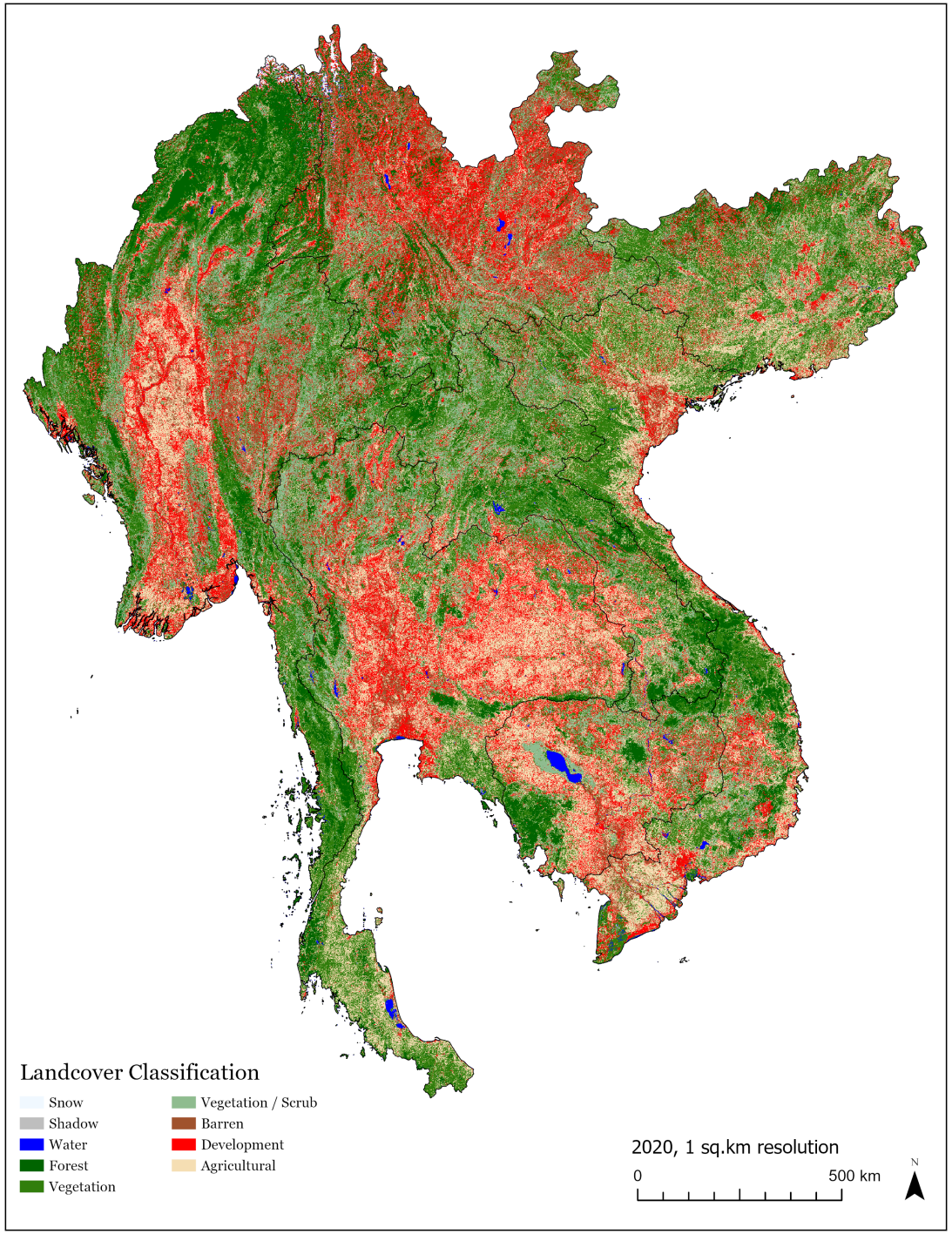
Earth Engine Data Processing Workflow

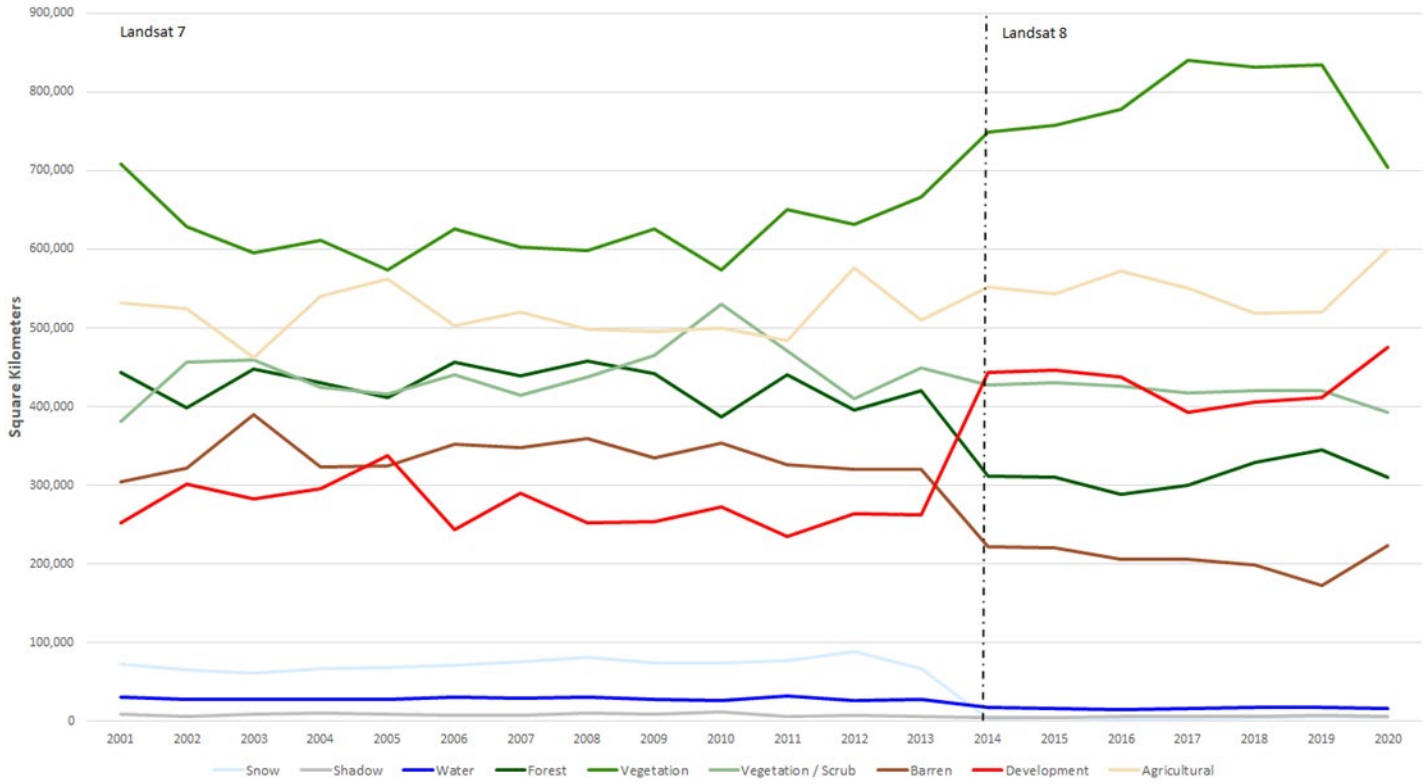
Earth Engine Data Source

Model Inputs

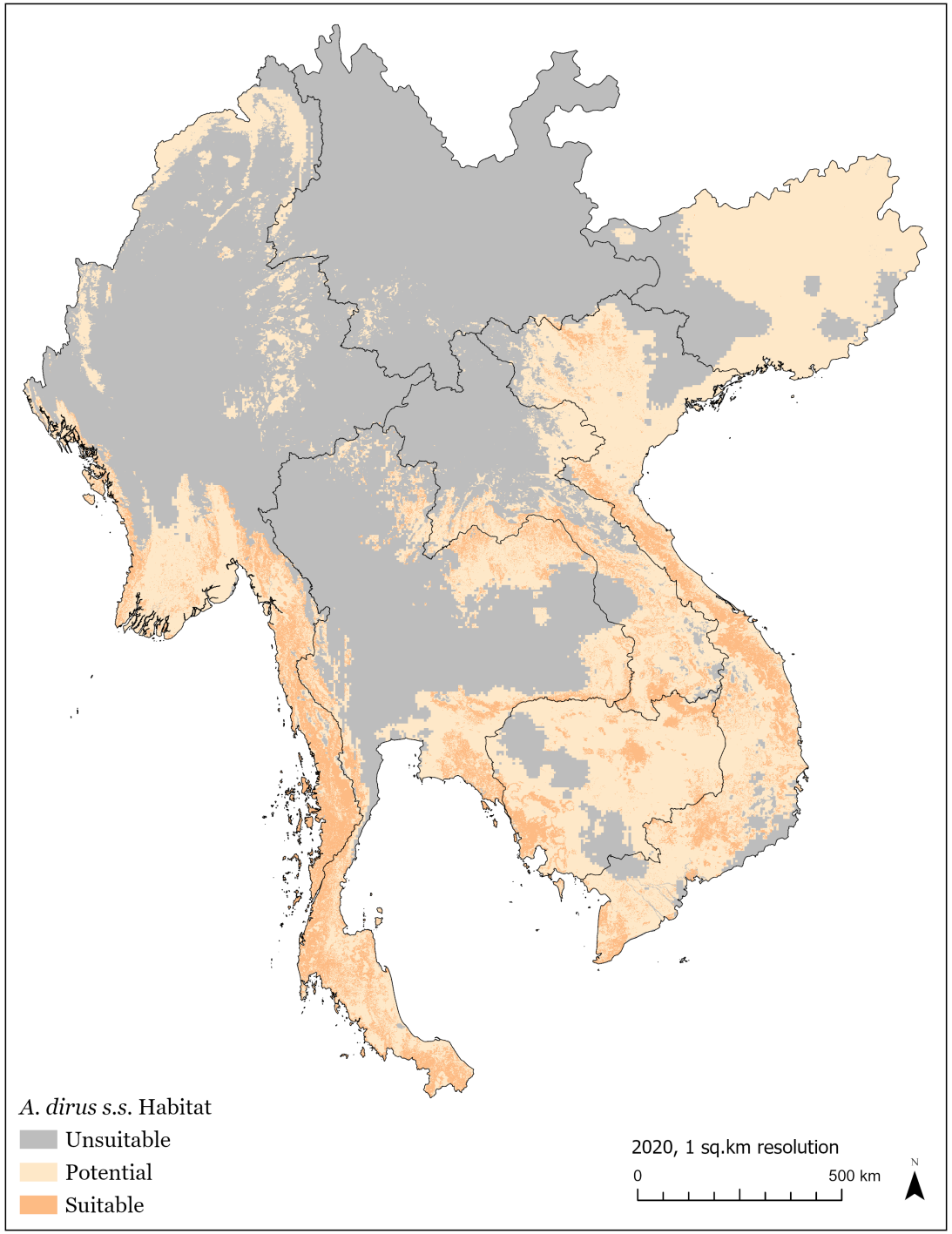
Model Outputs

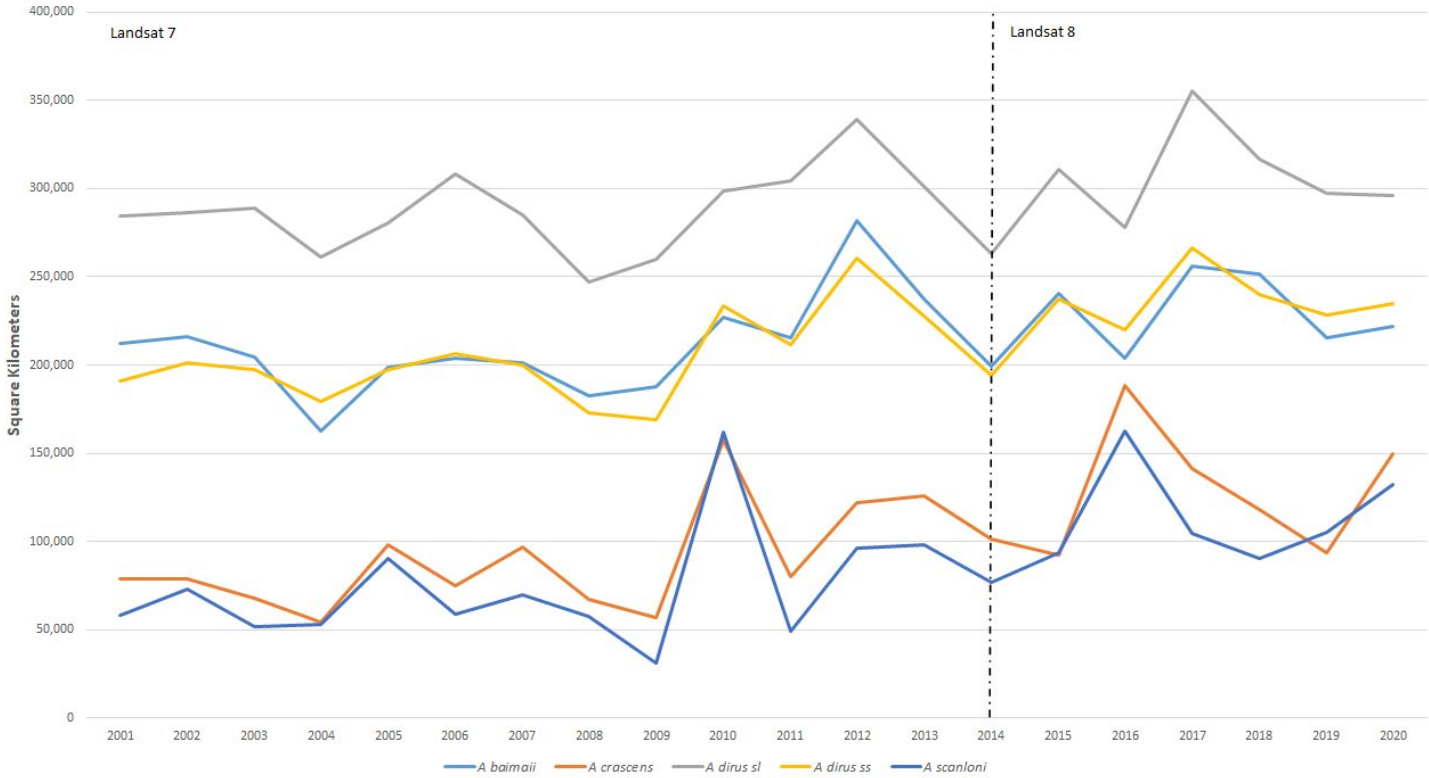
Landcover Classification





Habitat Classification





Sources of Error

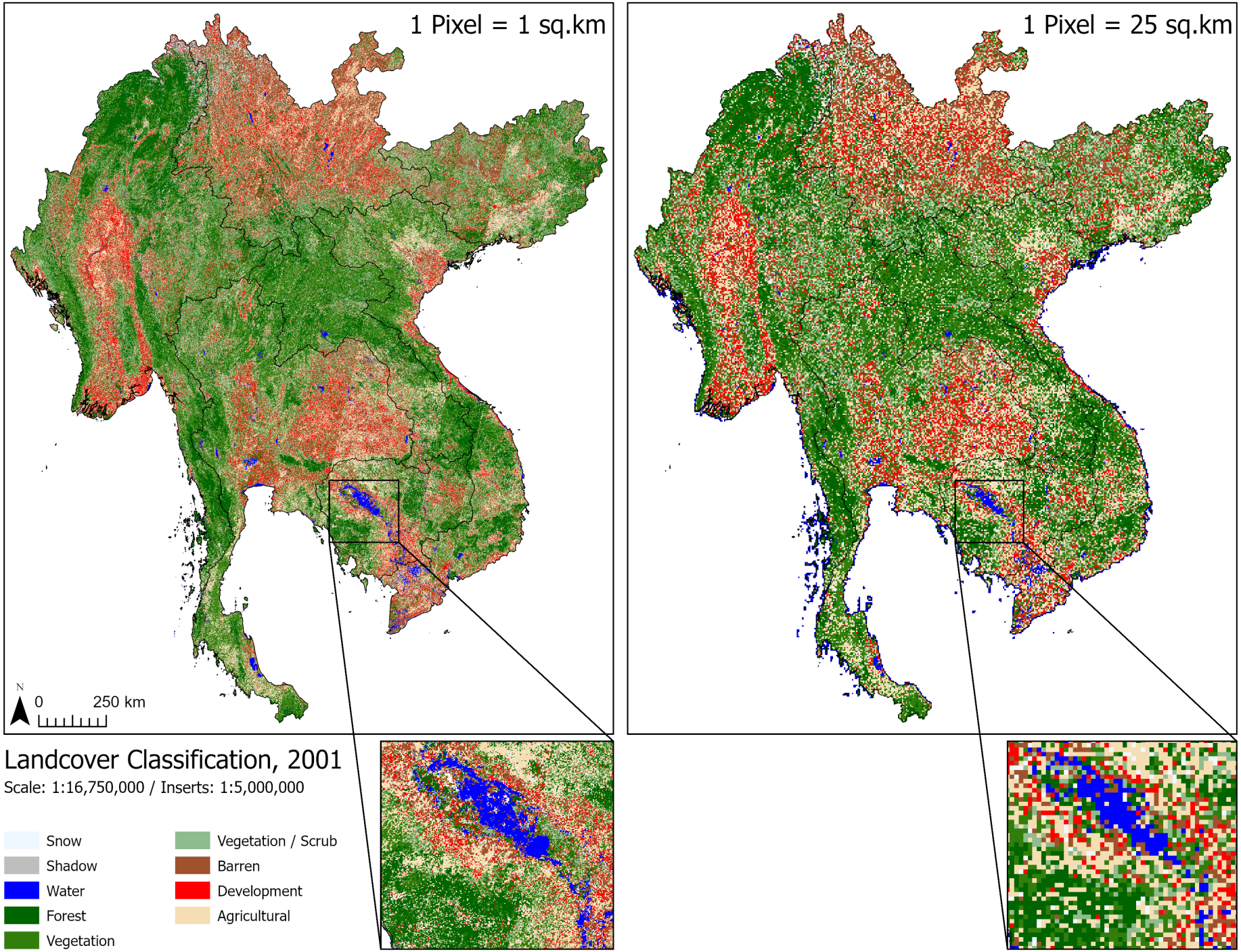
- Error can be introduced from a variety of sources

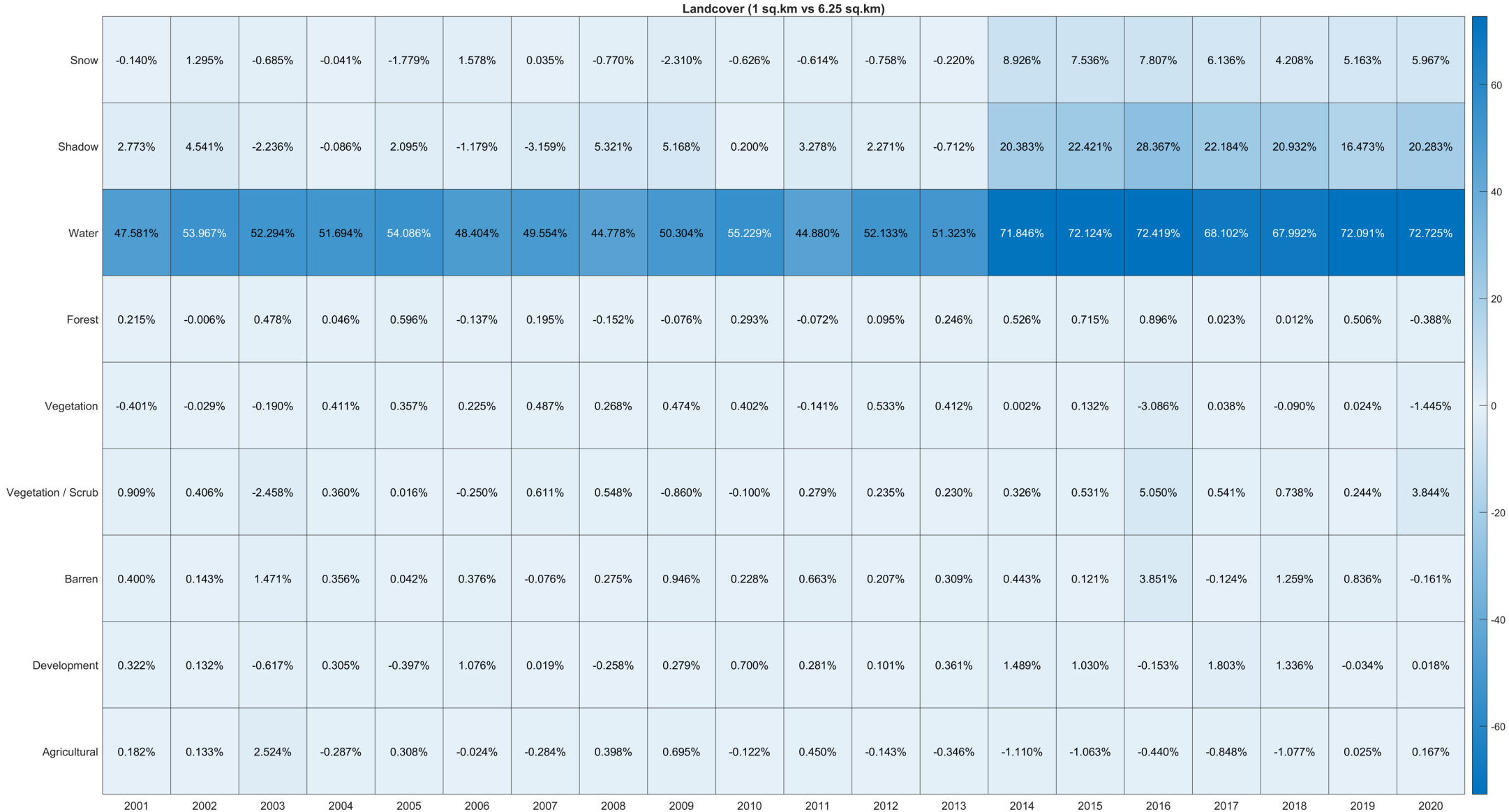
- Error inherent to the data we are working with:
  - Landsat
  - Climate
  - Literature

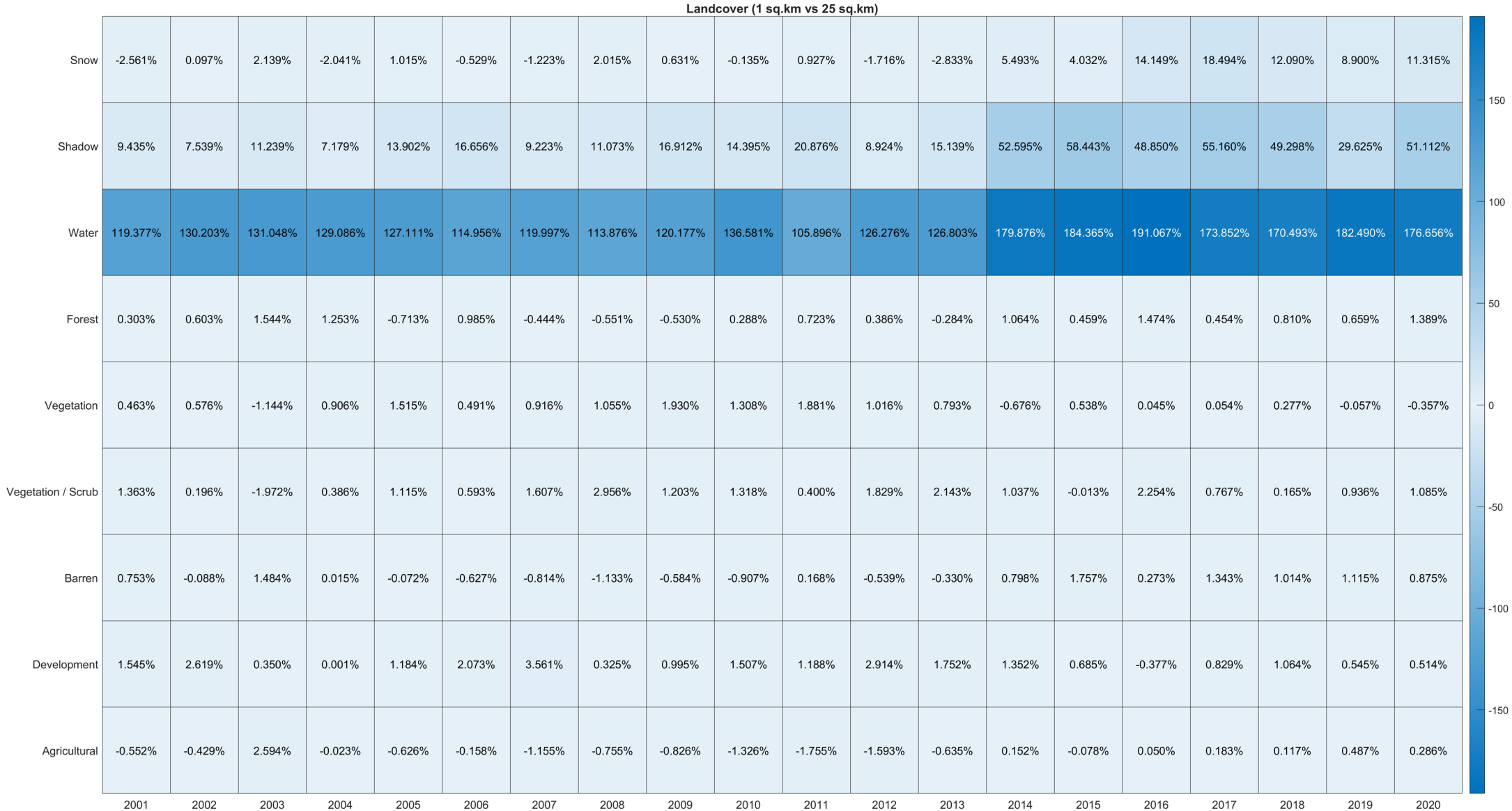
} *Sensitivity Analysis!*

- Error in how we:
  - Process the data
  - Interpret the data
  - Present our findings / analysis products

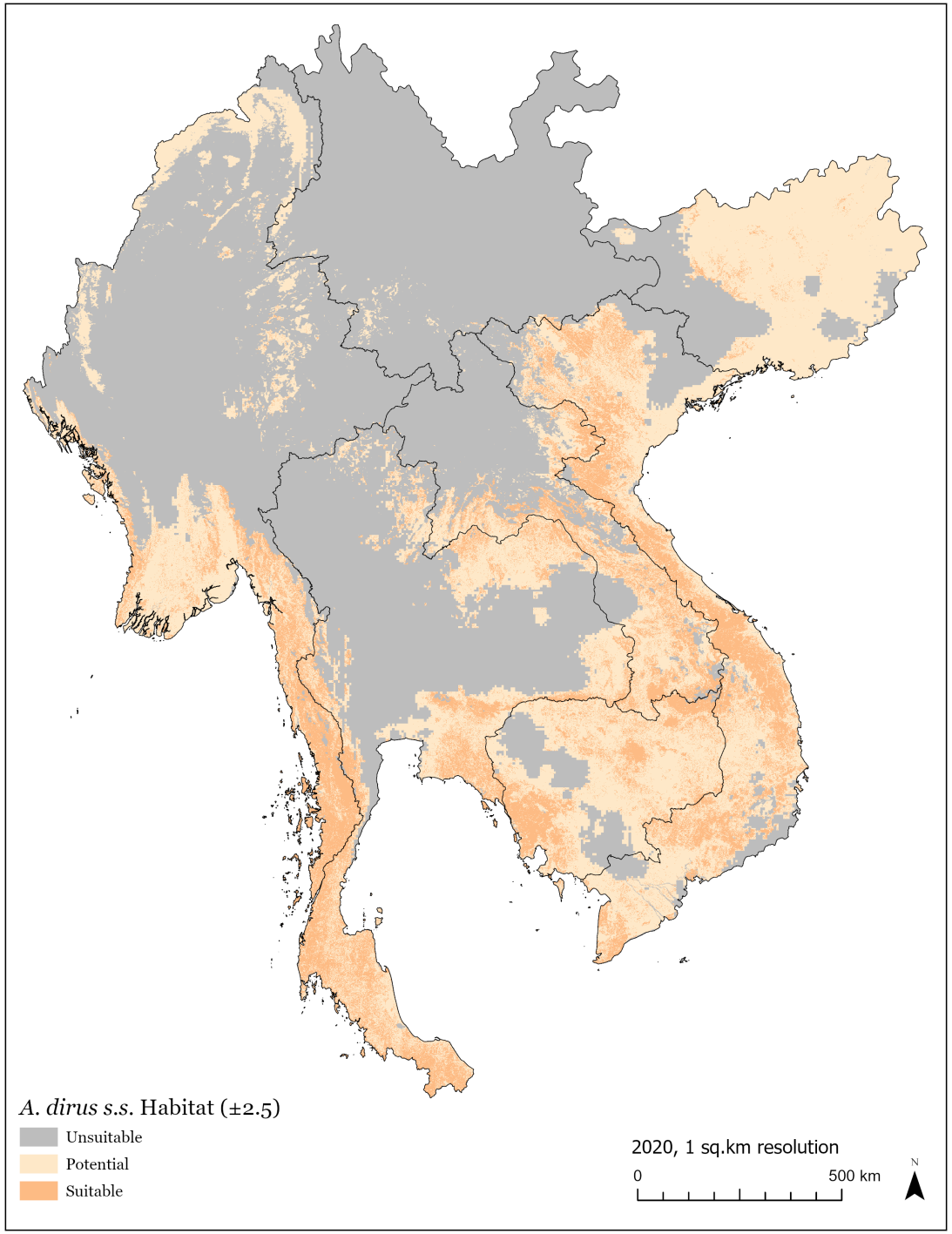
Landcover Classification

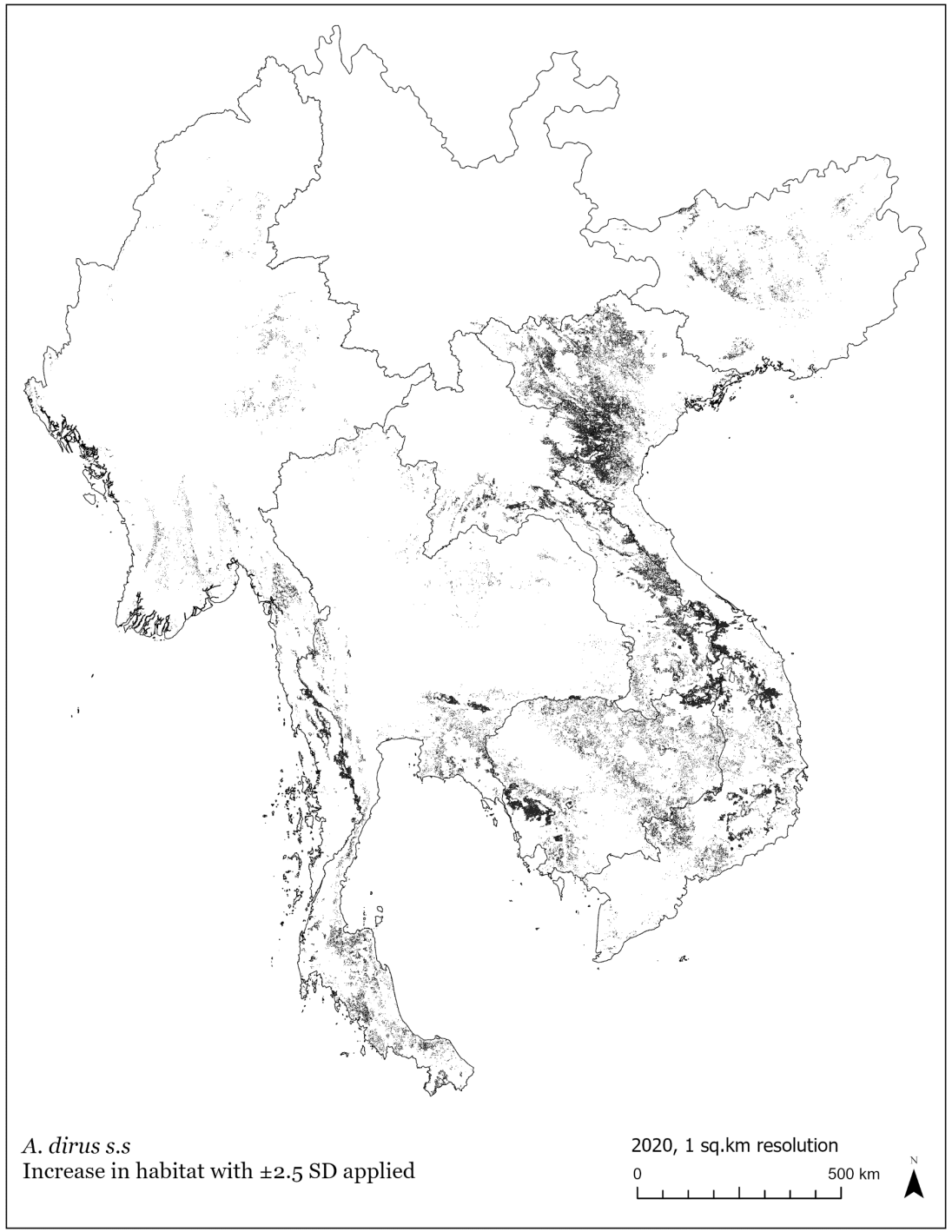

1 Pixel = 1 sq.km
1 Pixel = 25 sq.km
N
0
250 km
Landcover Classification, 2001
Scale: 1:16,750,000 / Inserts: 1:5,000,000
Snow
Shadow
Water
Forest
Vegetation
Vegetation / Scrub
Barren
Development
Agricultural

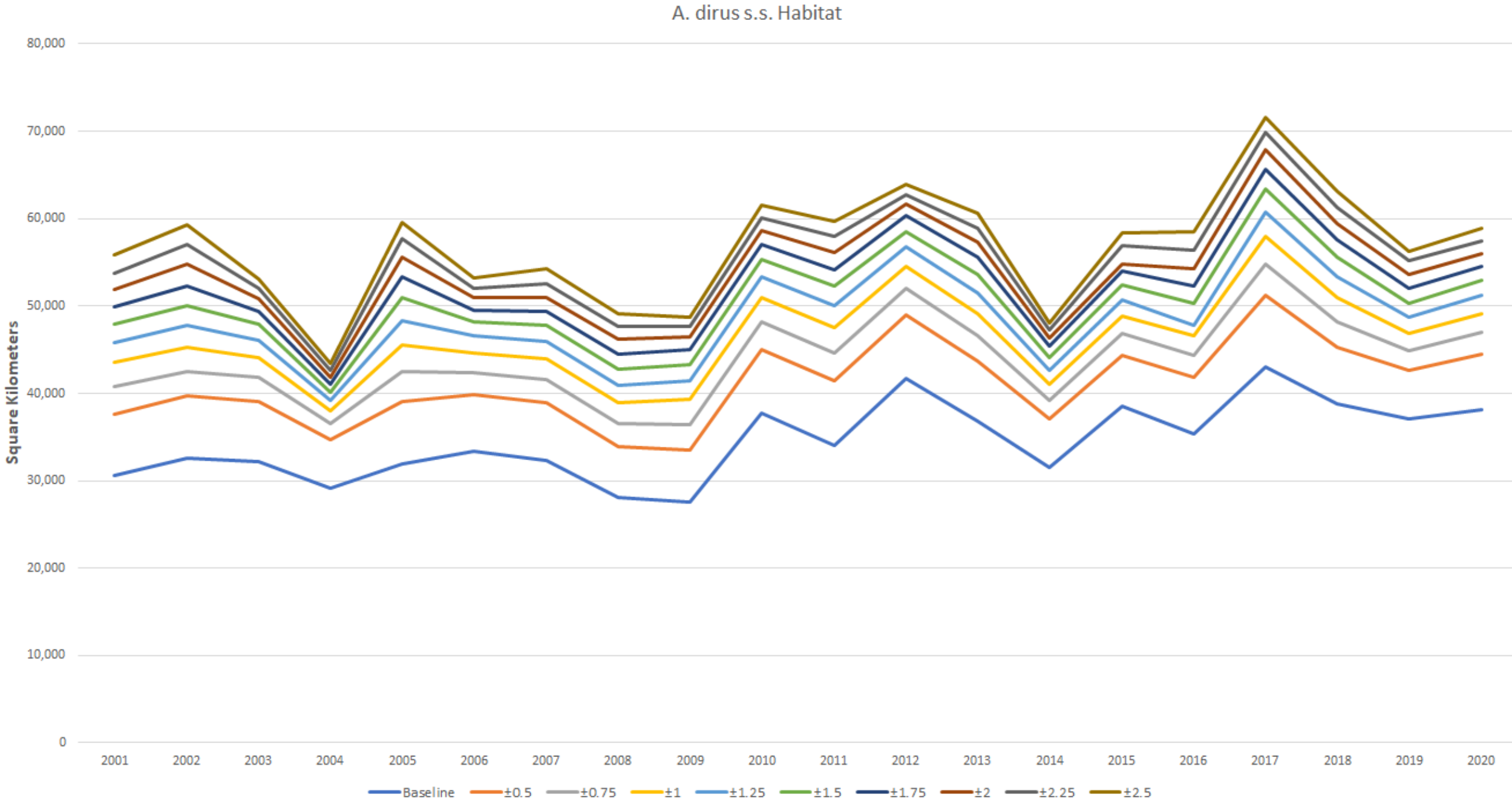

Landcover (1 sq.km vs 6.25 sq.km)
Snow -0.140% 1.295% -0.685% -0.041% -1.779% 1.578% 0.035% -0.770% -2.310% -0.626% -0.614% -0.758% -0.220% 8.926% 7.536% 7.807% 6.136% 4.208% 5.163% 5.967%
Shadow 2.773% 4.541% -2.236% -0.086% 2.095% -1.179% -3.159% 5.321% 5.168% 0.200% 3.278% 2.271% -0.712% 20.383% 22.421% 28.367% 22.184% 20.932% 16.473% 20.283%
Water 47.581% 53.967% 52.294% 51.694% 54.086% 48.404% 49.554% 44.778% 50.304% 55.229% 44.880% 52.133% 51.323% 71.846% 72.124% 72.419% 68.102% 67.992% 72.091% 72.725%
Forest 0.215% -0.006% 0.478% 0.046% 0.596% -0.137% 0.195% -0.152% -0.076% 0.293% -0.072% 0.095% 0.246% 0.526% 0.715% 0.896% 0.023% 0.012% 0.506% -0.388%
Vegetation -0.401% -0.029% -0.190% 0.411% 0.357% 0.225% 0.487% 0.268% 0.474% 0.402% -0.141% 0.533% 0.412% 0.002% 0.132% -3.086% 0.038% -0.090% 0.024% -1.445%
Vegetation / Scrub 0.909% 0.406% -2.458% 0.360% 0.016% -0.250% 0.611% 0.548% -0.860% -0.100% 0.279% 0.235% 0.230% 0.326% 0.531% 5.050% 0.541% 0.738% 0.244% 3.844%
Barren 0.400% 0.143% 1.471% 0.356% 0.042% 0.376% -0.076% 0.275% 0.946% 0.228% 0.663% 0.207% 0.309% 0.443% 0.121% 3.851% -0.124% 1.259% 0.836% -0.161%
Development 0.322% 0.132% -0.617% 0.305% -0.397% 1.076% 0.019% -0.258% 0.279% 0.700% 0.281% 0.101% 0.361% 1.489% 1.030% -0.153% 1.803% 1.336% -0.034% 0.018%
Agricultural 0.182% 0.133% 2.524% -0.287% 0.308% -0.024% -0.284% 0.398% 0.695% -0.122% 0.450% -0.143% -0.346% -1.110% -1.063% -0.440% -0.848% -1.077% 0.025% 0.167%
2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
60
40
20
0
-20
-40
-60


Landcover (1 sq.km vs 25 sq.km)
Snow -2.561% 0.097% 2.139% -2.041% 1.015% -0.529% -1.223% 2.015% 0.631% -0.135% 0.927% -1.716% -2.833% 5.493% 4.032% 14.149% 18.494% 12.090% 8.900% 11.315%
Shadow 9.435% 7.539% 11.239% 7.179% 13.902% 16.656% 9.223% 11.073% 16.912% 14.395% 20.876% 8.924% 15.139% 52.595% 58.443% 48.850% 55.160% 49.298% 29.625% 51.112%
Water 119.377% 130.203% 131.048% 129.086% 127.111% 114.956% 119.997% 113.876% 120.177% 136.581% 105.896% 126.276% 126.803% 179.876% 184.365% 191.067% 173.852% 170.493% 182.490% 176.656%
Forest 0.303% 0.603% 1.544% 1.253% -0.713% 0.985% -0.444% -0.551% -0.530% 0.288% 0.723% 0.386% -0.284% 1.064% 0.459% 1.474% 0.454% 0.810% 0.659% 1.389%
Vegetation 0.463% 0.576% -1.144% 0.906% 1.515% 0.491% 0.916% 1.055% 1.930% 1.308% 1.881% 1.016% 0.793% -0.676% 0.538% 0.045% 0.054% 0.277% -0.057% -0.357%
Vegetation / Scrub 1.363% 0.196% -1.972% 0.386% 1.115% 0.593% 1.607% 2.956% 1.203% 1.318% 0.400% 1.829% 2.143% 1.037% -0.013% 2.254% 0.767% 0.165% 0.936% 1.085%
Barren 0.753% -0.088% 1.484% 0.015% -0.072% -0.627% -0.814% -1.133% -0.584% -0.907% 0.168% -0.539% -0.330% 0.798% 1.757% 0.273% 1.343% 1.014% 1.115% 0.875%
Development 1.545% 2.619% 0.350% 0.001% 1.184% 2.073% 3.561% 0.325% 0.995% 1.507% 1.188% 2.914% 1.752% 1.352% 0.685% -0.377% 0.829% 1.064% 0.545% 0.514%
Agricultural -0.552% -0.429% 2.594% -0.023% -0.626% -0.158% -1.155% -0.755% -0.826% -1.326% -1.755% -1.593% -0.635% 0.152% -0.078% 0.050% 0.183% 0.117% 0.487% 0.286%
2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
150
100
50
0
-50
-100
-150

Habitat Identification

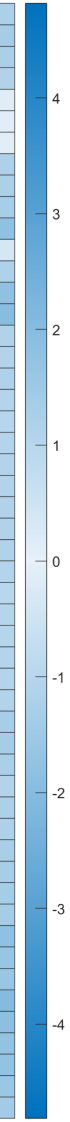

A. dirus s.s. Habitat (±2.5)
Unsuitable
Potential
Suitable
2020, 1 sq.km resolution
0
500 km
N


A. dirus s.s
Increase in habitat with ±2.5 SD applied
2020, 1 sq.km resolution
0
500 km
N


A. dirus s.s. Habitat
Square Kilometers
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Baseline
±0.5
±0.75
±1
±1.25
±1.5
±1.75
±2
±2.25
±2.5

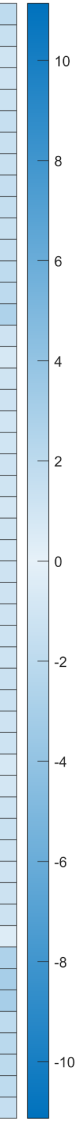
Habitat (1 sq.km vs 6.25 sq.km)

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
A. baimaii	0.455%	1.132%	2.083%	2.619%	1.517%	1.272%	1.429%	1.577%	2.305%	0.892%	0.160%	0.743%	0.954%	2.040%	2.212%	-1.243%	1.307%	1.447%	1.970%	1.239%
±0.5	0.344%	1.289%	2.081%	2.284%	1.287%	0.967%	1.199%	1.147%	1.865%	0.466%	0.013%	0.460%	0.838%	1.865%	1.805%	-0.988%	1.077%	1.235%	1.255%	1.345%
±0.75	0.288%	1.057%	1.907%	2.055%	1.195%	0.930%	1.201%	0.989%	1.660%	0.677%	0.152%	0.578%	0.861%	1.537%	1.733%	-1.041%	0.996%	1.183%	1.621%	1.256%
±1	0.236%	0.873%	1.767%	2.089%	1.189%	0.874%	1.025%	1.019%	1.462%	0.681%	0.084%	0.448%	0.758%	1.433%	1.695%	-0.875%	0.788%	1.123%	0.949%	1.123%
±1.25	0.053%	0.789%	1.729%	1.982%	1.291%	0.764%	0.969%	0.888%	1.344%	0.634%	0.051%	0.426%	0.618%	1.387%	1.594%	-1.022%	0.740%	1.022%	1.448%	0.115%
±1.5	0.018%	0.728%	1.741%	2.006%	1.168%	0.667%	0.838%	0.814%	1.131%	0.692%	-0.077%	0.460%	0.585%	1.466%	1.562%	0.319%	0.690%	1.006%	1.190%	-0.103%
±1.75	0.009%	0.694%	1.700%	1.881%	1.061%	0.609%	0.803%	0.810%	0.945%	0.617%	-0.292%	0.484%	0.498%	1.425%	1.502%	0.292%	0.076%	0.902%	1.241%	-0.111%
±2	-0.239%	0.696%	1.686%	1.840%	1.033%	0.728%	0.793%	0.760%	0.984%	0.728%	-0.333%	0.424%	0.552%	1.374%	1.582%	0.294%	0.698%	0.865%	1.098%	1.191%
±2.25	-0.282%	0.596%	1.576%	1.760%	1.077%	0.702%	0.677%	0.682%	1.038%	0.697%	-0.181%	0.377%	0.605%	1.393%	1.485%	0.192%	0.651%	0.916%	1.059%	1.208%
±2.5	-0.278%	0.510%	1.587%	1.675%	0.981%	0.620%	0.734%	0.736%	1.116%	0.743%	-0.094%	0.380%	0.618%	1.409%	1.547%	0.221%	0.584%	0.829%	1.121%	1.307%
A. crascens	1.094%	1.556%	3.491%	3.817%	2.355%	1.523%	1.881%	1.042%	1.493%	1.126%	-0.680%	1.186%	1.529%	1.981%	2.590%	0.776%	1.813%	1.897%	2.733%	1.823%
±0.25	-0.287%	2.434%	2.903%	4.815%	2.677%	2.215%	2.234%	0.451%	3.148%	-3.339%	1.733%	1.656%	2.284%	4.387%	3.126%	-2.058%	0.115%	0.478%	-0.014%	0.372%
±0.5	2.139%	3.150%	4.490%	4.280%	1.007%	2.556%	2.125%	0.346%	2.911%	-0.997%	2.102%	1.322%	2.572%	3.458%	2.128%	-1.211%	1.406%	0.069%	0.686%	1.152%
±0.75	1.101%	1.459%	3.523%	4.195%	0.775%	1.926%	2.311%	2.203%	3.395%	0.241%	1.844%	1.503%	1.580%	2.805%	2.545%	-0.455%	0.801%	0.588%	0.965%	1.791%
±1	0.932%	1.596%	3.150%	3.820%	0.811%	1.585%	2.026%	2.129%	2.933%	0.646%	1.773%	1.525%	1.259%	1.990%	2.814%	0.023%	0.862%	1.217%	0.940%	1.955%
A. dirus s.l.	0.274%	0.347%	1.273%	0.860%	0.718%	0.696%	0.775%	0.766%	1.143%	0.694%	0.367%	0.405%	0.848%	0.730%	-0.201%	0.307%	0.749%	0.676%	-0.329%	1.123%
±1	-0.072%	0.359%	1.379%	0.674%	0.668%	0.434%	0.345%	0.432%	0.527%	0.695%	0.117%	0.460%	0.999%	0.665%	-0.531%	0.639%	0.603%	0.665%	-0.641%	1.101%
±1.25	-0.100%	0.282%	1.185%	0.444%	0.809%	0.447%	0.210%	0.396%	0.486%	0.691%	0.132%	0.380%	0.950%	0.674%	-0.629%	0.525%	0.550%	0.652%	0.716%	1.153%
±1.5	-0.098%	0.197%	1.157%	0.525%	0.703%	0.394%	0.305%	0.473%	0.455%	0.819%	0.103%	0.344%	1.008%	0.657%	-0.564%	0.478%	0.575%	0.582%	0.835%	1.048%
±1.75	-0.086%	0.240%	1.156%	0.482%	0.641%	0.477%	0.337%	0.397%	0.572%	0.831%	0.189%	0.307%	0.985%	0.582%	-0.561%	0.516%	0.560%	0.495%	-0.780%	1.006%
±2	0.025%	0.236%	1.206%	0.533%	0.707%	0.434%	0.341%	0.390%	0.550%	0.833%	0.162%	0.344%	0.961%	0.533%	-0.622%	0.477%	0.540%	0.505%	0.949%	1.054%
±2.25	0.059%	0.237%	1.168%	0.633%	0.696%	0.489%	0.372%	0.314%	0.463%	0.798%	0.248%	0.421%	0.839%	0.627%	-0.710%	0.443%	0.481%	0.503%	0.873%	1.101%
±2.5	0.124%	0.295%	1.211%	0.673%	0.698%	0.473%	0.446%	0.306%	0.483%	0.801%	0.219%	0.294%	0.876%	0.580%	0.870%	0.358%	0.394%	0.458%	0.919%	1.087%
±2.75	0.204%	0.340%	1.140%	0.699%	0.756%	0.483%	0.381%	0.220%	0.500%	0.806%	0.283%	0.486%	0.850%	0.542%	0.783%	0.382%	0.455%	0.409%	0.968%	1.114%
±3	0.173%	0.284%	1.164%	0.604%	0.706%	0.491%	0.377%	0.259%	0.584%	0.791%	0.280%	0.502%	0.827%	0.542%	0.767%	-1.642%	0.502%	0.454%	1.051%	1.128%
±3.25	0.190%	0.268%	1.091%	0.655%	0.672%	0.529%	0.372%	0.256%	0.625%	0.702%	0.264%	0.453%	0.836%	0.476%	0.745%	0.420%	0.519%	0.533%	1.069%	1.132%
±3.5	0.195%	0.207%	1.077%	0.596%	0.715%	0.480%	0.374%	0.160%	0.630%	0.746%	0.177%	0.481%	0.850%	0.515%	0.718%	0.335%	0.624%	0.489%	1.068%	1.058%
±3.75	0.182%	0.164%	1.036%	0.564%	0.726%	0.435%	0.378%	0.179%	0.634%	0.728%	0.266%	0.464%	0.914%	0.507%	0.685%	0.376%	0.566%	0.423%	-1.383%	0.970%
±4	0.122%	0.175%	0.984%	0.553%	0.737%	0.407%	0.419%	0.238%	0.728%	0.773%	0.234%	0.458%	0.926%	0.607%	0.647%	0.367%	0.545%	0.380%	0.933%	1.022%
±4.25	0.249%	0.190%	0.981%	0.555%	0.719%	0.379%	0.399%	0.268%	0.704%	0.796%	0.230%	0.464%	1.004%	0.561%	0.689%	0.329%	0.581%	0.407%	0.991%	1.020%
±4.5	0.215%	0.163%	0.952%	0.567%	0.731%	0.421%	0.440%	0.429%	0.681%	0.816%	0.168%	0.475%	0.952%	0.616%	0.589%	0.365%	0.580%	0.413%	0.903%	1.066%
±4.75	0.118%	0.138%	0.934%	0.560%	0.735%	0.353%	0.471%	0.539%	0.711%	0.829%	0.159%	0.436%	0.960%	0.606%	0.641%	-1.960%	0.519%	0.378%	-1.576%	1.060%
±5	0.144%	0.135%	0.919%	0.631%	0.752%	0.358%	0.459%	0.609%	0.711%	0.827%	0.166%	0.465%	0.900%	0.680%	0.605%	0.303%	0.515%	0.339%	0.896%	1.087%
A. dirus s.s.	0.110%	1.091%	1.913%	1.654%	1.012%	0.983%	1.180%	1.182%	1.798%	1.097%	0.428%	0.236%	1.121%	1.477%	1.255%	0.401%	1.126%	1.060%	1.379%	1.319%
±0.5	0.076%	1.169%	1.636%	1.156%	0.687%	0.828%	0.942%	0.665%	1.394%	0.606%	0.255%	0.389%	1.201%	1.195%	1.005%	0.559%	0.605%	0.879%	1.302%	1.338%
±0.75	0.047%	0.757%	1.541%	0.956%	0.879%	0.711%	0.783%	0.619%	1.164%	0.660%	0.355%	0.519%	1.195%	1.006%	0.937%	0.548%	0.930%	0.831%	1.153%	1.249%
±1	0.082%	0.667%	1.434%	0.891%	0.809%	0.730%	0.719%	0.692%	1.086%	0.645%	0.366%	0.477%	1.069%	0.901%	0.869%	0.572%	0.780%	0.842%	1.239%	1.100%
±1.25	-0.056%	0.556%	1.268%	1.236%	0.728%	0.658%	0.658%	0.585%	1.053%	0.647%	0.417%	0.411%	0.964%	0.919%	0.813%	-0.970%	0.722%	0.781%	1.125%	1.235%
±1.5	-0.048%	0.420%	1.304%	1.272%	0.697%	0.625%	0.566%	0.500%	0.835%	0.681%	0.356%	0.089%	1.013%	1.020%	0.808%	0.325%	0.682%	0.714%	0.946%	1.192%
±1.75	-0.133%	0.442%	1.227%	1.221%	0.590%	0.485%	0.477%	0.610%	0.621%	0.511%	0.129%	0.389%	0.971%	1.040%	0.756%	0.329%	0.616%	0.705%	1.051%	1.271%
±2	-0.293%	0.499%	1.324%	1.228%	0.627%	0.564%	0.376%	0.591%	0.659%	0.593%	0.134%	0.399%	1.034%	0.930%	-0.324%	0.348%	0.644%	0.618%	1.060%	1.299%
±2.25	-0.304%	0.472%	1.219%	0.834%	0.800%	0.484%	0.233%	0.552%	0.615%	0.583%	0.169%	0.130%	0.998%	0.963%	0.824%	0.261%	0.619%	0.641%	0.861%	1.366%
±2.5	-0.289%	0.359%	1.253%	0.755%	0.706%	0.469%	0.271%	0.627%	0.595%	0.653%	0.155%	0.327%	1.062%	0.974%	0.857%	0.278%	0.595%	0.591%	-0.466%	1.340%
A. scanloni	-1.406%	0.851%	2.444%	0.584%	2.472%	0.221%	-0.088%	0.776%	-2.455%	0.816%	-3.784%	-0.207%	0.766%	1.329%	0.492%	1.194%	1.120%	1.473%	2.540%	1.791%
±0.25	2.341%	2.004%	4.626%	1.462%	3.024%	2.755%	2.431%	1.053%	1.576%	1.696%	-0.571%	0.992%	1.565%	0.576%	2.757%	1.531%	3.512%	4.481%	3.282%	1.639%
±0.5	1.542%	1.040%	3.313%	1.761%	2.705%	2.303%	2.949%	2.149%	1.456%	1.931%	-0.748%	1.815%	2.444%	1.252%	2.968%	1.875%	3.840%	2.976%	3.292%	1.636%
±0.75	1.827%	1.827%	3.437%	2.374%	2.229%	1.827%	1.977%	1.073%	2.192%	1.395%	0.645%	1.186%	2.463%	2.321%	2.387%	0.998%	3.566%	2.863%	3.426%	2.013%
±1	1.538%	1.778%	3.307%	2.787%	2.628%	1.421%	2.009%	1.333%	2.284%	1.060%	0.270%	1.227%	2.414%	2.749%	2.356%	1.197%	2.575%	2.283%	2.753%	1.874%
±1.25	0.643%	1.560%	3.011%	2.664%	2.237%	1.402%	1.407%	1.178%	1.661%	0.681%	0.762%	0.908%	1.819%	2.741%	2.325%	0.750%	2.103%	1.873%	2.433%	1.743%
±1.5	0.941%	1.471%	2.988%	2.617%	1.886%	1.634%	1.519%	1.353%	1.463%	1.124%	0.672%	0.735%	1.673%	2.446%	2.001%	0.740%	1.939%	1.536%	2.130%	1.714%
±1.75	0.519%	1.303%	2.919%	2.436%	1.608%	1.307%	1.323%	1.532%	2.033%	1.008%	0.631%	0.666%	1.527%	2.364%	1.519%	0.748%	1.585%	0.884%	1.888%	1.587%
±2	0.307%	1.878%	2.623%	2.198%	1.527%	1.016%	1.189%	1.239%	2.258%	0.886%	0.430%	0.722%	1.342%	2.012%	0.520%	1.029%	1.305%	1.319%	2.016%	1.445%



Habitat (1 sq.km vs 25 sq.km)

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
A. baimaii	2.235%	1.008%	3.178%	4.809%	1.307%	4.513%	2.498%	2.815%	3.884%	2.015%	4.707%	0.717%	1.518%	3.411%	3.725%	3.044%	2.626%	1.715%	2.371%	1.882%
±0.5	1.849%	0.854%	2.765%	4.914%	1.051%	3.523%	2.135%	1.819%	3.714%	1.800%	3.379%	0.541%	1.079%	2.466%	3.136%	3.078%	1.993%	1.420%	2.352%	1.470%
±0.75	1.565%	0.976%	2.564%	4.519%	1.182%	3.131%	1.689%	1.761%	3.494%	1.607%	3.193%	0.810%	1.203%	2.027%	3.004%	2.852%	1.753%	1.299%	2.316%	1.073%
±1	1.461%	0.877%	2.224%	4.281%	1.377%	3.151%	1.445%	1.497%	3.057%	1.544%	2.732%	0.605%	1.373%	2.180%	2.904%	2.786%	1.552%	1.330%	2.218%	1.150%
±1.25	1.176%	0.843%	2.454%	4.223%	1.917%	3.248%	1.464%	1.135%	2.772%	1.724%	2.738%	0.958%	1.153%	1.784%	2.903%	2.294%	1.658%	1.055%	2.108%	1.299%
±1.5	1.242%	1.081%	2.492%	4.032%	1.832%	3.165%	1.725%	0.890%	2.667%	1.815%	2.783%	1.012%	1.049%	1.706%	3.059%	2.290%	1.425%	1.318%	2.087%	1.490%
±1.75	1.155%	1.304%	2.458%	4.165%	1.722%	2.830%	1.799%	1.107%	2.624%	1.787%	2.660%	0.950%	0.904%	1.772%	2.590%	2.215%	1.395%	1.050%	2.292%	1.393%
±2	1.110%	1.282%	2.435%	4.064%	2.020%	2.849%	1.443%	0.964%	2.474%	1.881%	2.696%	0.880%	0.626%	1.816%	2.569%	2.181%	1.374%	1.109%	1.891%	1.419%
±2.25	0.962%	1.475%	2.396%	3.822%	2.082%	2.971%	1.457%	0.987%	2.231%	1.770%	2.926%	0.861%	0.626%	1.662%	2.505%	2.433%	1.486%	1.200%	1.736%	1.579%
±2.5	0.882%	1.710%	2.443%	3.505%	2.913%	3.118%	1.698%	1.092%	2.448%	1.822%	3.147%	0.919%	0.675%	1.752%	2.540%	2.481%	1.487%	1.254%	1.687%	1.638%
A. crascens	1.205%	3.434%	3.133%	5.258%	3.764%	5.295%	0.641%	1.862%	3.910%	1.594%	4.612%	1.770%	0.913%	2.166%	4.255%	2.407%	3.873%	2.246%	3.599%	1.460%
±0.25	4.052%	1.153%	6.781%	11.136%	5.145%	7.684%	1.693%	3.343%	4.609%	0.526%	5.501%	0.778%	3.740%	5.635%	5.158%	0.146%	1.370%	3.334%	1.470%	-1.691%
±0.5	2.406%	2.526%	6.192%	9.558%	4.120%	5.310%	1.623%	5.413%	5.418%	0.640%	7.123%	1.449%	2.113%	5.924%	2.801%	-0.012%	3.431%	2.994%	1.578%	1.880%
±0.75	4.063%	2.421%	4.638%	7.258%	4.284%	5.250%	2.342%	3.844%	3.888%	2.226%	7.229%	2.178%	0.697%	4.323%	4.281%	2.218%	3.251%	3.040%	2.806%	1.924%
±1	3.614%	2.995%	3.455%	7.285%	3.156%	5.294%	2.472%	4.225%	4.329%	1.083%	7.059%	1.000%	0.098%	3.546%	3.657%	3.106%	2.497%	2.937%	3.348%	2.695%
A. dirus s.l.	1.564%	0.397%	0.879%	1.970%	0.807%	1.777%	0.284%	1.565%	2.912%	0.805%	2.847%	0.825%	0.035%	1.271%	1.588%	1.683%	1.249%	1.725%	0.352%	1.153%
±1	0.987%	0.925%	0.688%	2.358%	1.533%	1.642%	0.460%	1.245%	1.829%	0.566%	2.893%	1.034%	-0.026%	1.171%	1.441%	1.576%	1.084%	1.236%	0.519%	0.783%
±1.25	0.876%	1.087%	0.627%	2.169%	0.909%	1.694%	0.180%	1.166%	1.783%	0.829%	2.730%	1.054%	0.174%	1.145%	1.392%	1.576%	1.202%	1.215%	0.387%	1.055%
±1.5	0.833%	1.276%	0.886%	2.332%	1.023%	1.655%	0.506%	1.242%	1.919%	0.939%	2.675%	1.096%	0.157%	0.963%	1.569%	1.695%	1.066%	1.220%	0.331%	1.169%
±1.75	0.989%	1.225%	0.830%	2.071%	1.796%	1.593%	0.529%	0.994%	1.945%	1.036%	2.643%	1.143%	0.106%	0.936%	1.708%	1.708%	1.115%	1.307%	0.666%	0.988%
±2	0.873%	1.140%	0.826%	2.363%	1.328%	1.485%	0.587%	0.724%	1.971%	1.054%	2.770%	1.314%	0.124%	0.799%	1.660%	1.750%	1.142%	1.326%	0.686%	1.027%
±2.25	0.986%	1.315%	1.052%	1.739%	1.303%	1.483%	0.759%	0.491%	1.974%	1.133%	2.799%	1.136%	0.178%	0.746%	1.651%	1.720%	1.084%	1.327%	0.805%	1.159%
±2.5	1.064%	1.182%	0.988%	1.890%	1.484%	1.457%	0.703%	0.569%	2.127%	1.067%	2.697%	1.263%	0.449%	0.960%	1.526%	1.740%	1.128%	1.366%	0.702%	1.060%
±2.75	1.022%	1.123%	0.909%	1.970%	1.880%	1.636%	0.792%	0.614%	1.992%	0.961%	2.627%	1.274%	0.627%	0.936%	1.631%	1.689%	1.118%	1.307%	0.838%	0.898%
±3	0.816%	1.215%	0.965%	2.006%	1.944%	1.720%	0.935%	0.639%	2.042%	0.912%	2.494%	1.274%	0.789%	0.977%	1.518%	1.628%	1.149%	1.346%	0.968%	1.075%
±3.25	0.682%	1.218%	0.932%	2.019%	1.584%	1.691%	0.742%	0.955%	2.148%	0.794%	2.574%	1.320%	0.695%	1.071%	1.683%	1.709%	0.945%	1.211%	0.977%	1.015%
±3.5	0.575%	1.316%	0.914%	1.996%	1.551%	1.631%	0.666%	0.994%	2.142%	0.964%	2.663%	1.384%	0.621%	1.216%	1.785%	1.646%	1.051%	1.284%	0.940%	1.147%
±3.75	0.767%	1.280%	0.888%	1.892%	1.505%	1.729%	0.562%	0.910%	2.092%	1.119%	2.689%	1.367%	0.681%	1.109%	1.732%	1.582%	1.007%	1.186%	0.801%	1.156%
±4	0.951%	1.256%	0.907%	1.826%	1.616%	1.751%	0.581%	0.964%	2.133%	1.128%	2.665%	1.404%	0.718%	1.132%	1.620%	1.481%	1.260%	1.247%	0.716%	1.142%
±4.25	0.988%	1.256%	0.898%	1.791%	1.621%	1.744%	0.769%	1.035%	2.089%	0.953%	2.658%	1.516%	0.762%	1.206%	1.656%	1.475%	1.338%	1.291%	0.688%	1.218%
±4.5	1.140%	1.279%	0.888%	1.959%	1.534%	1.695%	0.752%	1.212%	2.187%	1.145%	2.579%	1.495%	0.814%	1.350%	1.614%	1.462%	1.256%	1.349%	0.673%	1.192%
±4.75	1.134%	1.232%	0.919%	2.071%	1.486%	1.757%	0.790%	1.441%	2.158%	1.036%	2.646%	1.605%	0.813%	1.320%	1.648%	1.533%	1.321%	1.276%	0.658%	1.311%
±5	1.119%	1.287%	0.906%	2.135%	1.455%	1.872%	0.863%	1.562%	2.199%	1.048%	2.645%	1.585%	0.754%	1.524%	1.563%	1.558%	1.282%	1.242%	0.709%	1.325%
A. dirus s.s.	2.535%	0.666%	2.049%	3.638%	0.374%	4.107%	1.448%	2.961%	3.869%	1.198%	4.175%	1.283%	0.632%	2.602%	1.955%	2.602%	1.802%	1.861%	0.698%	1.157%
±0.5	1.829%	0.428%	1.389%	3.183%	0.481%	2.922%	1.038%	1.962%	3.337%	1.003%	3.382%	1.147%	0.342%	1.604%	1.462%	2.603%	1.378%	1.331%	1.025%	1.186%
±0.75	1.485%	0.454%	1.256%	2.887%	0.720%	2.480%	0.829%	1.825%	3.338%	0.771%	3.255%	1.290%	0.391%	1.019%	1.528%	2.344%	1.190%	1.463%	0.772%	0.765%
±1	0.438%	0.453%	0.878%	2.689%	1.323%	2.436%	0.435%	1.541%	3.086%	0.813%	2.857%	0.964%	0.437%	1.197%	1.655%	2.259%	1.130%	1.455%	0.844%	0.882%
±1.25	1.132%	0.257%	1.009%	3.121%	1.059%	2.386%	0.433%	1.347%	2.745%	0.975%	2.807%	1.368%	0.502%	0.871%	1.738%	1.954%	1.087%	1.155%	0.895%	1.195%
±1.5	0.904%	0.466%	1.129%	2.926%	0.809%	2.419%	0.743%	0.958%	2.396%	1.292%	2.906%	1.423%	0.415%	0.713%	1.687%	1.669%	0.944%	1.450%	0.802%	1.368%
±1.75	0.896%	0.747%	0.889%	3.012%	1.069%	2.158%	0.877%	1.370%	2.186%	0.991%	2.907%	1.309%	0.473%	0.740%	1.387%	1.542%	0.955%	1.113%	0.954%	1.224%
±2	0.955%	0.822%	0.855%	2.856%	1.159%	2.113%	0.691%	1.299%	2.127%	0.963%	2.741%	1.325%	0.258%	0.826%	1.537%	1.652%	0.977%	1.010%	0.721%	1.134%
±2.25	0.883%	0.979%	0.760%	2.488%	1.202%	2.150%	0.647%	1.269%	1.914%	1.003%	2.724%	1.352%	0.325%	0.835%	1.513%	1.830%	1.143%	1.158%	0.527%	1.248%
±2.5	0.823%	1.179%	0.959%	2.243%	1.184%	2.204%	0.999%	1.350%	2.046%	0.903%	2.877%	1.342%	0.418%	0.771%	1.516%	1.872%	1.048%	1.173%	0.444%	1.247%
A. scanloni	-2.454%	1.622%	1.507%	2.482%	2.954%	4.631%	-0.762%	-0.391%	4.373%	1.836%	-3.860%	1.539%	2.223%	2.912%	2.821%	3.127%	2.857%	-0.062%	1.250%	0.395%
±0.25	5.333%	1.896%	5.377%	6.426%	1.803%	5.319%	4.530%	6.599%	5.033%	0.438%	4.921%	1.423%	3.338%	1.339%	1.985%	2.789%	5.667%	4.006%	2.898%	2.680%
±0.5	4.868%	2.825%	3.114%	2.043%	0.938%	2.587%	1.276%	2.221%	6.037%	3.667%	3.011%	3.343%	4.504%	3.237%	5.578%	4.024%	6.903%	3.604%	2.236%	3.015%
±0.75	4.263%	3.200%	4.738%	2.968%	2.364%	3.561%	2.667%	2.544%	6.481%	2.167%	4.050%	3.399%	3.016%	2.504%	4.356%	3.718%	6.327%	3.723%	2.767%	3.015%
±1	4.241%	2.674%	4.874%	4.478%	1.476%	4.756%	2.083%	3.658%	6.002%	2.167%	5.004%	3.177%	2.830%	3.343%	4.193%	3.094%	4.634%	3.271%	3.196%	1.910%
±1.25	3.619%	2.180%	5.314%	4.695%	2.174%	5.195%	2.282%	2.735%	6.400%	1.715%	4.036%	2.546%	2.817%	3.347%	4.330%	3.055%	4.232%	2.988%	2.883%	2.089%
±1.5	3.561%	1.855%	4.932%	5.249%	1.828%	4.891%	2.343%	3.479%	5.691%	1.892%	4.467%	2.007%	2.365%	3.764%	4.328%	3.409%	3.635%	2.285%	2.769%	2.001%
±1.75	2.947%	1.484%	4.513%	5.348%	1.797%	5.017%	2.320%	2.828%	5.282%	1.654%	4.708%	2.008%	1.969%	3.376%	3.360%	3.751%	3.143%	1.963%	2.135%	1.871%
±2	2.394%	1.703%	3.486%	5.530%	1.609%	4.710%	2.250%	2.895%	4.955%	1.880%	4.473%	1.467%	1.217%	3.439%	3.183%	3.647%	2.443%	1.863%	2.206%	1.579%



Discussion

- Landcover may be sensitive to the satellite used for imaging
  - This may be correctable through additional supervised classification
- Both landcover and habitat are sensitive to the resolution of the pixels
  - However, for the purposes of identifying habitats this may not be a concern
- Earth Engine has some idiosyncrasies:
  - Exporting from deployed applications
  - Batch processing can take awhile

Next Steps

- Manuscript currently in progress

- Codebase is open source, BSD 3-Clause License
  - https://github.com/rjzupkoii/gms-malaria

- Earth Engine App is deployed and supported
  - https://rzupko.users.earthengine.app/view/gms-malaria

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Earth Engine App
https://rzupko.users.earthengine.app/view/gms-malaria

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GitHub Repository
https://github.com/rjzupkoii/gms-malaria

Thanks!

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